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Control of Mushroom Diseases and Weed Fungi

FIRST STAGE OF THE BROWN SPOT DISEASE OF MUSHROOMS

PENNSYLVANIA DEPARTMENT OF HEALTH BIOLOGICAL INSTITUTE
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Summary of Control Measures

Mushroom houses can be made sanitary by fumigation with formaldehyde, 3 lbs. to 1000 cu. ft., or burning flowers of sulphur, 2 lbs. to 1000 cu. ft. To assure an effective concentration of the fumes requires tight sealing of all cracks and ventilators, rapid evolution of the fumes, and thorough diffusion. These requirements are more likely to be attained if the fumes are evolved outside the house with an apparatus designed for the purpose and then blown inside near the floor.

Fumigation needs to be supplemented by drenching floors and spraying doorways and bottom beds with a fungicidal solution, especially if fumes of formaldehyde or sulphur are evolved within the house. One of the following may be used: 4 lbs. of copper sulphate dissolved in 50 gals. of water, 2½ per cent crude carbolic acid, or 16 lbs. of formaldehyde to 50 gals. of water. Spraying all inside surfaces and structures with a fungicidal solution can be substituted for fumigation. These treatments are also suitable for packing sheds.

Treat adjacent yards, composting ground, and other exterior parts of the plant that may have become infested with fungous spores, using one of the following fungicidal solutions at the rate of at least a quart to the square foot: 8 lbs. of copper sulphate dissolved in 50 gals. of water, 7 ozs. of mercuric chloride dissolved in 50 gals. of water, or 2½ per cent crude carbolic acid.

Deposits of spent compost or waste mushroom fragments should not be left near a mushroom house, as they are ready sources of disease.

Before refilling is begun, empty, clean, and disinfect, as far as possible, all houses that may be infested with disease or weed fungi. This is particularly important in a series of adjoining houses.

A temperature of ~~130° to~~ 140° F. after filling is necessary to kill any harmful fungi introduced with the compost. Electric fans set horizontally at the top of the center aisle are usually essential to overcome the differences of temperature between top and bottom beds. Avoid unnecessarily high temperatures, above 140° ~~to 150°~~ F.

Observe sanitary precautions about houses from the time the compost cools for spawning so that the spores of fungi will not be carried to clean beds. Wash contaminated hands and clothes, and disinfect soiled baskets or other utensils. This is important for the exclusion of the *Verticillium* disease (brown spot), *Mycogone* disease (bubbles), bacterial blotch, and white plaster mold.

Sterilize the soil for casing, or be certain that it is obtained from a field that has not been contaminated with spent mushroom manure, waste, or drainage from houses having disease. While this applies particularly to the *Mycogone* disease, it is also important in preventing the introduction of other diseases or molds.

Endeavor to maintain the temperature of bearing beds within the range that is optimum for mushrooms, 55° to 58° F. Many diseases and weed molds become serious on account of abnormally high temperatures. Avoid warm season crops unless an efficient cooling and ventilating system is installed.

Provide efficient ventilation so that excessive humidity and precipitation of moisture in bearing houses may be readily removed or prevented. A desirable humidity is 88 to 90 per cent. Ventilation is most efficient when the outside temperature is below that inside. Surplus moisture upon mushrooms in the pinhead and button stages should dry readily if brown spot and bacterial blotch are to be held in check.

Watch for the first occasional or local development of brown spot, bubbles, or mildew. Pick all good mushrooms within an area of disease, and remove and destroy all diseased specimens. Spray the diseased area with 1 to 50 dilution of formaldehyde and cover with heavy paper for a day. Then allow the area to dry and aeriate a week before watering again. It is possible to treat whole beds in this manner.

Control of readily disseminated weed molds, particularly white plaster mold and olive-green mold *(Chaetomium olivaceum),* depends chiefly on favorable composting of the manure. If the spawn starts and grows well, it will take possession of the compost in spite of considerable contamination by these molds. If the composting is not favorable and the spawn is retarded, the molds are likely to predominate. It is advisable to test the reaction, or pH, of the compost just before the beds are cooled for spawning to see whether the heating has reduced the pH low enough for the spawn to grow readily. The nearer the pH is to neutral (pH 7.0) the more likely it is that the spawn will outgrow the molds.

Control of heat-resistant weed molds, like truffle, requires a thorough disinfection of the composting ground and other contaminated places. Spray the interior of infested houses with a fungicidal solution.

Insects are important carriers of fungous spores, hence control of insects is an aid in checking the spread of harmful fungi.

Filling houses but once a year is a distinct advantage in the control of harmful fungi because the mushroom crop can be grown entirely within a cool season, when temperature and moisture conditions can be easily kept optimum; many fungi, especially *Verticillium* and white plaster mold, disappear largely by drying during the months that the houses are empty; and there is less likelihood that picking will continue in infested houses while other houses are being refilled.

This bulletin gives detailed descriptions of the *Verticillium* disease (brown spot) and mildew caused by *Dactylium sp.*

Control of Mushroom Diseases and Weed Fungi[1]

W. S. Beach

Growers of the common edible mushroom, *Agaricus (Psalliota) campestris* L., suffer serious loss through parasitic and weed fungi. Among the fungi parasitic on the mushroom, the most important at present is a species of *Verticillium*.[2] This is the chief cause of discoloration, or "brown spot," which often injures entire flushes during warm humid periods. This disease affects the quality of mushrooms largely, but it may progress into a dry leathery decay, or it may produce certain distortions of growth that resemble the more familiar *Mycogone* disease, or "bubbles." *Mycogone perniciosa* Magnus, the cause of bubbles, has become less important as a parasite since its principal source and the conditions favoring it are better known.

A species of the fungus *Dactylium*[3] causes an uncommon but destructive soft decay, or "mildew." In England, Wood (21) reports evidence that species of *Fusarium* attack mushrooms. *Bacterium tolaasi* (Paine) Elliott produces a limited amount of discoloration called "brown blotch." Recently, another bacterial disease has attracted attention; it is fittingly described by the common name "bacterial pit."

In all diseases of mushrooms, the parts principally affected are the fruiting caps in their various stages of development. For the sake of brevity and convenient identification, the chief features of the different diseases are presented in synoptic form (Table 1).

Many fungi associated with mushroom culture act merely in the capacity of weeds infesting the composted horse manure or the casing soil. These are called "weed molds." Since they confine their attack to non-living organic matter, they belong in that class of organisms known as saprophytes. They are often serious competitors of the mushroom for nutriment, or they prevent normal growth of the spawn by harmful changes produced in the condition of the compost. The principal weed molds are briefly described in the probable order of the damage they incur in Table 2.

There are certain organisms, both fungous and bacterial, the presence of which in manure is not harmful. On the other hand, some are useful since their activity is necessary for composting, or for the fermentation which makes manure favorable for the growth of mushroom mycelium. There are also organisms present which are neither harmful or useful.

Characteristics of Diseases and Weed Fungi

Only such descriptions of the various fungi and the injuries they cause will be given as will suffice for identification (Tables 1 and 2). Exceptions are made where adequate descriptions are not published, or are not available.

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[1] Authorized for publication June 1, 1937.

[2] This *Verticillium* is similar to *V. malthousei* Ware and may be identical.

[3] This *Dactylium* has been tentatively classified as *D. dendroides* Bull.

TABLE 1. SYNOPSIS OF MUSHROOM DISEASES AND KEY FOR IDENTIFICATION

Common names of the disease	*Scientific name of the causal organism*	*Characteristics of the disease and the causal organism*	*Source and dissemination of the causal organism*	*Environmental conditions that favor the development of the disease*
Mycogone disease, bubbles (Fig. 1).	*Mycogone perniciosa* Magnus	Mushrooms partly or completely malformed, having various distorted shapes, often puffball-like; white cottony fungous growth on the gills or other infected parts; drops of dark amber liquid exuded upon the surface; final wet decay with an offensive odor.	General development in a house shows that the field where the casing soil was obtained has become spore infested by spent manure, waste or drainage from houses having bubbles. Occasional infections may arise from spores carried by insects or insanitary workmen.	Houses too warm or above 60° F. during production. The severity of bubbles increases with the rise of temperature, 100 per cent infection being possible above 60° F., while at 50° F. there may be only occasional specimens of disease.
Verticillium disease, brown spot, fungous spot (Fig. 1 and frontispiece).	*Verticillium sp.*	Irregular, cinnamon-brown spots, which enlarge and merge, develop over the surface of the mushrooms; brown areas later show depressions and become gray to white as the parasite forms spores; a dry, leathery, rather superficial decay without offensive odor follows. Some stems are bent or split, and many mushrooms become merely small puffball-like structures.	*Verticillium* remains widely distributed about mushroom plants when waste is not removed and contaminated ground is not disinfected. Although the organism may be completely destroyed within houses by manure heat or disinfection, spores are carried into the houses again by wind, insects and unsanitary workmen.	Infection is favored by too great humidity, the precipitation of moisture and poor ventilation after watering. The disease is worst in warm, humid weather. Loss is increased by failure to remove promptly all dead buttons, butts and infected waste from beds.
Bacterial spot, brown blotch. (Fig. 2).	*Bacterium tolaasi* (Paine) Elliott	Pale, yellow spots, later becoming a rich chocolate brown, develop on the surface of the mushrooms. Discoloration or decay penetrates only 1/25 to 3/25 of an inch below the surface. These symptoms undergo no further change.	*Bacterium tolaasi* is carried into clean houses from contaminated yards or similar sources. It appears to be similar to *Verticillium* in its source and dissemination.	Bacterial spot is favored by the same conditions as favor *Verticillium*, except that it is adapted to lower temperatures.
Bacterial pit. (Fig. 2).	*Bacterium sp.* (apparently parasitic)	Small pits or depressions occur in variable number over the surface of the mushrooms. Glistening masses of bacteria lie within the pits. A narrow zone of tissue about each pit is discolored or exhibits slight decay.	The source of bacterial pit has not been investigated. It may be similar to that of *Verticillium* and bacterial spot.	Not investigated.
Mildew, soft decay (Fig. 2).	*Dactylium sp.* (A facultative parasite)	A downy or fluffy, rapidly growing mold overspreads the casing soil and attacks the mushrooms in its course. The mushrooms collapse in a soft decay. Agar cultures of the fungus are marked by an orange to red color.	Mildew has not been observed in Chester County, Pa., but it is reported to occur on mushroom beds in abandoned coal mines. Specimens have been received from mushroom houses in Detroit, Mich.	Mildew develops profusely under normal mushroom house conditions as shown by experiments.
Damping-off.	**Fusarium spp.*	The mushrooms have a pithy, withered character with the stem showing a dark brown to black color extending from the base upward. The mushrooms are small, or they may stop growth in the button stage. They exhibit a glossy and somewhat darker tint than normal.	Species of *Fusarium* are natural inhabitants of soil and would probably occur in casing soil unless it was treated.	Species of *Fusarium* become injurious to plants under very warm conditions. It is not probable that temperatures below 60° F. would permit their serious development. Whether these fungi cause significant damage to mushrooms in America has not been determined.

* The parasitism of *Fusarium oxysporum* Schl. and *F. martii* App. and Wr. upon mushrooms is indicated by a recent investigation in England (21).

TABLE 2. SYNOPSIS OF THE PRINCIPAL WEED MOLDS ASSOCIATED WITH MUSHROOM CULTURE

Common name of the mold	*Scientific name of the mold*	*Characteristics of the mold and the injury it causes*	*Sources and dissemination of the mold*	*Environmental conditions that favor the development of the mold*
White plaster mold, flour mold (Fig. 4).	*Monilia fimicola* Cost. and Matr.	The mold grows through the compost of new beds, usually ahead of the spawn. At first, its appearance does not differ markedly from spawn, but later it breaks into white powdery masses that resemble crumbling plaster. The growth of the spawn is inhibited or fails altogether.	The spores of white plaster mold are carried into houses by wind, insects and workmen from exterior parts of the plant, or from other infested houses. This occurs at the time of spawning or thereafter as the fungus does not survive heat above 120° F.	White plaster mold is largly associated with very alkaline compost. This condition itself can delay or inhibit spawn growth. The mold maintains and possibly increases unfavorable alkalinity. Very damp bed surfaces favor the start of the mold.
Truffle (Fig. 3)	*Pseudobalsamia microspora* Diehl and Lambert	Cream colored wefts or layers of mold develop within the compost, behind side bed boards or on the casing soil after the beds are bearing. Later spore containing bodies develop amid the mold. These have a calf-brain appearance or resemble the edible truffle. Further mushroom production stops within the area of mold growth.	The original source of truffle is apparently infested manure which contaminates the composting ground. The spores survive the higher temperatures of fermenting manure. Whether they survive sulphur or formaldehyde fumigation has not been definitely proved.	Truffle develops only after composting or spawn growth has reduced the alkalinity of the manure until it is but slightly alkaline or acid. It is favored by very warm houses, 83° F. being its optimum. Damp manure favors its start. Rapid spawn growth seems to stimulate it.
Olive-green mold (Fig. 3).	*Chaetomium olivaceum* C. and E.	This mold develops in the compost of new beds after spawning and produces a musty odor. Its growth is very rapid. Spore containing bodies which appear like tiny balls of mold are observable on the surface of straws. Spawn growth is retarded or fails altogether. This mold is a common destroyer of cellulose.	The spores of the olive-green mold are widely distributed in nature and await only dampness to begin growth upon such cellulose materials as straw, paper, cloth, wood, etc.	The olive-green mold grows most readily on slightly acid materials but it adapts itself to very alkaline manure. Its growth is said to be favored by manure that has heated to a very high temperature, or is insufficiently composted. The mold is rarely troublesome in properly composted manure.
Brown plaster mold (2).	*Myriococcum praecox* Fries	Dull white, plaster-like patches of mold develop on the surface of the compost or the casing soil. These patches become tan and finally cinnamon-brown. Spawn growth and mushroom production is retarded within the mold areas.	Brown plaster mold is usually brought into houses with the casing soil, although it possibly survives in the compost when beds do not heat above 130° F.	Brown plaster mold appears to be adapted to the normal conditions maintained in mushroom houses. It appears to be less common with the improvement in sanitation and the higher temperatures now obtained in houses while heating.
Cat's ear fungus (Fig. 4).	*Pleurotus passeckerianus* Pilat	Small patches of thin, white mold develop in the casing soil. The fruiting stage appears later as slowly growing, delicate, white, ear-like structures. This fungus inhibits mushroom production to a small extent.	The source of cat's ear fungus appears to be casing soil which has not been sterilized.	The cat's ear fungus grows well under normal mushroom house conditions.
Green molds.	*Trichoderma spp.* and *Penicillium spp.*	These green molds develop largely upon old butts and dead buttons at first. They then attack healthy mushrooms slightly, at least at the bases. The presence of the molds seems to be toxic to mushrooms. The nature of the parasitism, if any, has not been determined. It is possible that species of *Trichoderma* and *Fusarium* produce similar effects.	Species of *Trichoderma* and *Penicillium* are common inhabitants of soil and would usually be present in casing soil unless it had been disinfected.	Species of *Trichoderma* and *Penicillium* are favored by acid soils. Very wet or continuously wet casing soil with the accumulation of dead buttons and old butts of mushrooms favors the severe development of these molds.

The *Verticillium* Disease, or Brown Spot

This is wholly superficial in its initial attack upon partly developed mushrooms (see front cover). Cinnamon brown spots with irregular outline develop at different points of infection over the surface of the pileus (cap) and stipe (stem). The separate spots enlarge and coalesce with adjacent spots, so that eventually the whole surface may become discolored. This discoloration is conspicuous on the white variety of mushrooms now commonly grown, hence the change from brown or cream varieties to white has attracted more attention to the *Verticillium* disease. The tissues beneath the discolored surface are affected to a depth of only a very small fraction of an inch at first. Peeling off the diseased surface at this stage leaves the remainder of the mushroom reasonably edible.

When spotted mushrooms are left standing, either upon the beds after picking or in the market baskets, the mycelium of the parasite penetrates more deeply into the tissues, and depressions of the surface then become evident (Fig. 1, e). Meanwhile, brown surfaces change to dull white or gray, beginning in limited areas which gradually enlarge. This change of color is due to the abundant formation of the microscopic conidiophores (spore stalks) and spores of the parasite upon the diseased surfaces. The character of this surface development of the parasite is better revealed in the case of gill infection since the host tissues are dark in color (Fig. 1, d). As the disease continues to progress, infected tissues show a rather dry, leathery decay, but there is no offensive odor, such as accompanies the *Mycogone* disease. Occasionally, the decay may extend through a mushroom.

When infection begins on the side of the stipe, or along the margin of the veil, the cessation of growth by infected tissues results in a bending of the stipe and a tilting of the pileus. Later, the stress within the expanding tissues causes portions of the stipe to split off along its length (Fig. 1, g). Splitting of stipes is a rather common feature of the *Verticillium* disease.

When casing soil is heavily infested with *Verticillium* spores arising from previous infections, many mushrooms become infected in their youngest stages, even in the pinhead stage. This early infection results in distortions of growth that resemble those produced by the *Mycogone* disease, or bubbles (compare c, e and f, Fig. 1). The infection of the top of the pinhead checks the growth of the pileus, while the stipe widens into a puffball-like malformation. A cross section of one of these puffball-like malformations is shown in Fig. 1, h, in which the dark tissues reveal the region invaded by the mycelium of *Verticillium.*

In general, the puffball-like malformations produced by *Verticillium* are smaller than those that characterize the *Mycogone* disease. The latter is further distinguished by a relatively abundant development of cottony white mycelium of the parasite upon the surface of the infected specimens, by the exudation of drops of dark amber liquid and the final, wet, foul-smelling decay. With *Verticillium* infection, the puffball-like mushrooms remain as tough, leathery structures until attack by molds and bacteria ultimately brings decay. *Verticillium* usually does not produce an abundant development of

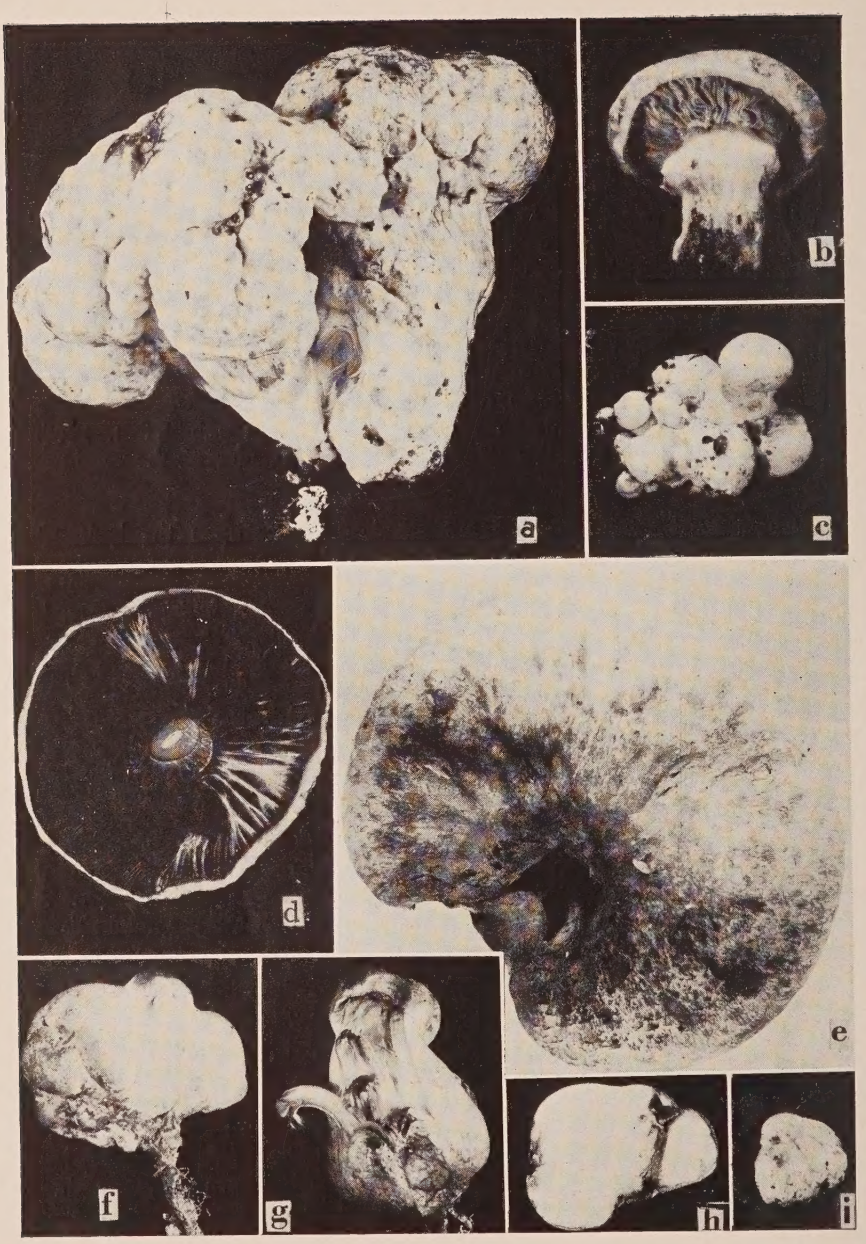

FIG. 1. COMPARISON OF THE *MYCOGONE* DISEASE, OR BUBBLES, WITH THAT CAUSED BY *VERTICILLIUM*

a. Characteristic specimen of *Mycogone* disease, ¾ natural size.
b. Mushroom showing deformed gills, a common characteristic of the *Mycogone* disease.
c. Group of mushrooms with *Mycogone* disease, showing the drops of dark, amber exudate, ½ natural size.
d. Mushroom gills showing infection by *Verticillium*, the scant white growth of the parasite being revealed against the dark color of the gills.
e. Advanced stage of *Verticillium* infection showing the depression of the pileus tissues.
f. Puffball-like mushroom resulting from *Verticillium* infection in the pinhead stage, natural size.
g. Mushroom with a split stipe and a tilted pileus caused by *Verticillium* infection along the margin of the veil, natural size.
h. Longisection of a puffball-like mushroom, the dark tissues showing the region of *Verticillium* infection, natural size.
i. Puffball-like mushroom resulting from *Verticillium* infection in which the mycelium and spores of the parasite show more than common development over the surface, giving a white effect not readily distinguishable from *Mycogone* disease.

mycelium upon the surface of infected mushrooms. Growth is limited largely to spore formation which gives the surface a gray, mat appearance (Fig. 1, d and e).

In 1923, Orton (13) studied the brown spot then prevalent in several Chester County mushroom houses. Through isolation and inoculation experiments, he found that the spotting and discoloration were due principally to the parasitism of a fungus, a species of *Verticillium*. Simultaneously, he made inoculations with cultures of bacteria isolated from discolored mushrooms. One culture, which was probably *Bacterium tolaasi* (Paine) Elliott, produced a type of brown spot more mild and superficial than did *Verticillium*. Orton concluded that not more than five per cent of mushroom spotting was due to bacteria; that *Verticillium* caused the most of the damage.

Orton caught the spores of *Verticillium* in the ventilator outlets of infested houses and also isolated the organism from the soil near a cannery. He found that spraying infested beds with dilute bordeaux mixture gave a marked reduction of brown spot on the next flush and did not injure the mushrooms significantly.

The results of the present investigation are in accord with those of Orton. Observations for several years show that *Verticillium* causes most of the damage known as brown spot or fungous spot. Bacterial spot such as Tolaas describes (19), and the brown blotch ascribed by Paine (14) to *Bacterium tolaasi* (Paine) Elliott, appears to be of slight importance as a rule. The fungous spot illustrated by Styer (17) is evidently the *Verticillium* disease.

Ware (20) describes a disease of mushrooms in England and names the parasite *Verticillium malthousei*. In essential respects, that disease appears similar to the one occuring in Pennsylvania, except that Ware's description and certain of his illustrations indicate a greater mycelial development of the parasite upon the surface of infected specimens than is common in this country. Ware also reports *Verticillium malthousei* to have somewhat larger spores than those measured as representative of the parasite here. It is possible, that these differences are merely varietal.

Mildew *(Dactylium sp.)*

Specimens of this disease were first received from badly infested mushroom houses in Detroit, Michigan. The specimens consisted of sections of the compost with casing soil bearing the infected mushrooms. Their appearance was quite like the illustration (Fig. 2, a) which shows the result of an inoculation with the parasite after it had been obtained in pure culture. From a single area of inoculation upon the casing soil, the fungus spread to most of the other experimental plots in the house. Its dissemination seemed to be much like that of *Verticillium*, chiefly through watering, picking, and the movement of mushroom flies. During the spread of the fungus, the temperature of the house was 58° to 60° F., and the humidity was 92 per cent.

The illustration shows that the mycelium of the *Dactylium* grows over the casing soil as well as attacking the mushrooms. This indicates that the fun-

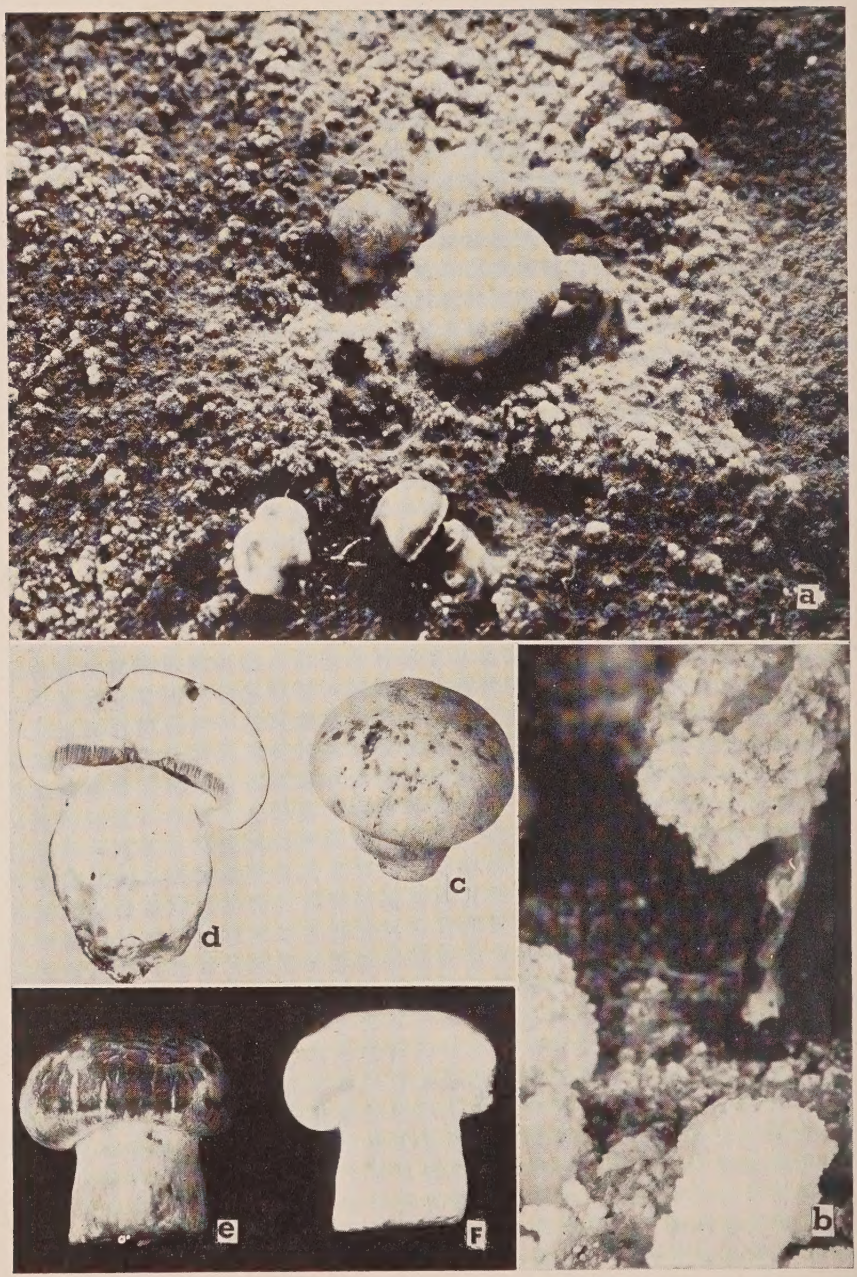

FIG. 2. VARIOUS MUSHROOM DISEASES

a. Mildew or soft decay of mushrooms caused by *Dactylium sp.* showing the fungus overspreading the casing soil and attacking a group of mushrooms which have collapsed.

b. Later stage of the mildew showing mushrooms heavily overgrown with the mycelium of *Dactylium*.

c. Bacterial pit of mushrooms showing the small pits upon a cap.

d. Longisection of a mushroom affected with bacterial pit.

e. Bacterial spot, or brown blotch, of mushrooms caused by *Bacterium tolaasi*.

f. The same mushroom specimen as *e* in longisection showing the superficial nature of bacterial spot.

gus is a facultative parasite. The decay of the mushrooms is rapid. After their collapse, the mycelium of the parasite develops very abundantly so that the mushrooms appear like balls of cotton (Fig. 2, b). This mycelium is delicate and apparently requires rather damp conditions. Spore production is prolific upon numerous upright conidiophores. The fungus is close to *Dactylium dendroides* Bull. in morphological features except that the spores have two to three cross walls rather than one, as in the latter species. Author Correction!

Since soil seemed to be the most probable source of this *Dactylium,* a change of source of casing soil, or sterilization, was suggested. These measures appear to have been successful.

Pleurotus passeckerianus Pilat,[4] the Cat's Ear Fungus

This weed fungus is quite often observed in both American and European mushroom beds. In one filling of the experimental house at The Pennsylvania State College, the fungus occurred here and there on nearly all beds. Apparently the casing soil contained the fungus. The organism did comparatively little harm to mushroom production.

Bacterial Pit

This disease was observed more or less commonly in Chester County mushroom houses during 1936 and 1937 and was the cause of slight damage. Whether it is entirely distinct from bacterial spot or brown blotch has not been determined, although differences in symptoms would indicate this to be the case. In many instances, mushrooms show bacterial pit while the remainder of the exterior surface is white and free of any discoloration that resembles bacterial blotch (Fig. 2, c). It is difficult to understand how this situation would arise if the same organism were the cause of both diseases.

Control Measures

Many progressive growers are comparatively successful in keeping damage at a minimum. There is need, however, for more general and more effective application of control measures, especially broadening their scope. The following suggestions are based on experimental work conducted at The Pennsylvania State College and tests in commercial mushroom plants.

Sources of Harmful Fungi.— After a few years of operation, it is possible for mushroom plants to become heavily infested with various disease and weed organisms introduced through channels of trade. The spores of these fungi lodge about the plants or in their vicinity. Not only in the houses, but also in various places where mushrooms or compost are handled, there are liable to occur organisms that await suitable conditions to grow. There is evidence that the interior of houses is usually made sanitary by measures now followed, but the same cannot be said of the exterior of many mushroom plants. Neglect of waste disposal is often aggravated by poor drainage and the presence of buildings and materials difficult to rid of infestation.

[4] Passecker, Fritz. Schadliche Pilze in Champignonkulturen (Das Katzenohr). Der Obst— und Gemusebau, 78 Jahrgang, Heft 2, Feb., 1932.

The frequent recurrence of the *Verticillium* disease at periods of the year when moisture and temperature are favorable is a sign that the causal organism survives in the vicinity, as in the soil of mushroom house yards. White plaster mold may be rather similar in its recurrence, although less seasonal. Soil is the chief carrier of the *Mycogone* disease. Several of the weed molds appear to have the same source.

Since manure is composted in the open, it is exposed to contamination by various fungi unless proper measures are taken to destroy them. The only definite knowledge about the dissemination of truffle is that it can be carried in manure and survives the heat of fermentation in the beds as well as in the compost heaps. Certain fungi, like the olive-green mold, *Chaetomium olivaceum,* are rather universal in distribution. The majority of the fungi under consideration are now more or less common in mushroom growing centers.

Early Control Measures.— The foremost method of disease control has been cleaning and disinfecting bed boards and house interiors prior to refilling with fresh compost. Less attention has been given to similar measures for manure yards, the vicinity of houses, packing sheds, and the soil used for casing. During the early years, or when mushroom plants were isolated, further efforts to exclude harmful organisms may have been unnecessary. With the gradual extension of mushroom growing, proximity of other plants and wider, as well as heavier, infestation by various organisms has made more precautions necessary. Greater attention to all the sources of fungi, the manner of spore dispersal and the conditions promoting their growth is required. A need for a well-rounded sanitary program has arisen.

Disinfection of Houses.— Fumigation with formaldehyde is probably the earliest method of disinfecting mushroom houses in Pennsylvania. The solution was boiled off in a closed vessel, usually a metal cask, and the vapor led into the tightly sealed house by a pipe through the wall. The vapor was released from solution, also, with potassium permanganate or sodium chlorate, the ingredients being placed in receptacles set in the center aisle. The rate of use of formaldehyde is usually 3 lbs. to 1000 cu. ft. of space, although recommendations have varied considerably (3, 17). When potassium permanganate or sodium chlorate is used, a large part of the formaldehyde is lost in the chemical reaction, but the gas is very rapidly evolved. Some growers still prefer formaldehyde fumigation, as there is no risk of fire.

Later, formaldehyde was displaced largely by burning sulphur within houses because it was cheaper, more convenient, and destroyed insects as well as fungi. The grade of sulphur known as "commercial" was used at the rate of 5 lbs. to 1000 cu. ft. The better-burning flowers of sulphur is much superior and permits a substantial reduction in the amount required, or a rate of 2 lbs., as shown by the experiments of Davis and Young (7). These workers point out the difficulty of securing rapid diffusion and high concentration of sulphur fumes when sulphur is burned on the ground of aisles. The heat of combustion causes the fumes to rise and there may not be sufficient concentration to kill organisms near the floor. This defect may be overcome largely by burning the sulphur in a special burner outside and blowing the fumes through a lead-in pipe near the floor.

Fumigation by burning sulphur is advisable not only when the houses are empty but also during the "peak" heat of fermentation of the manure after the beds are filled. In the latter case, the purpose is solely for the destruction of insects and the dosage should never exceed 1.5 to 2 lbs. of flowers of sulphur to 1000 cu. ft. (18).

Since about 1930, spraying interiors with fungicidal solutions has been practiced more or less. The reappearance of truffle in successive crops of mushrooms prompted a greater use of fungicidal solutions, as there were indications that this mold survived in bed boards in spite of formaldehyde or sulphur fumigation. Such survival lacks definite proof as yet. Solutions of formaldehyde, copper sulphate, crude carbolic acid and lime sulphur, as well as bordeaux mixture, have been used.

Disinfection of Floors, etc.— There are certain parts of mushroom houses where fumigation may fail to destroy all fungi completely. The same is probably true of manure heat after filling. Effectiveness of these measures depends upon the thorough diffusion of lethal fumes or heated air. In fumigation, proper concentration is essential. This is obtained by sealing all ventilators and cracks and by evolving the sulphur or formaldehyde fumes rapidly. Some means of forced circulation increases effectiveness, hence blowing the fumes in near the floor is advantageous.

In many instances, proper attention is not given to these details of fumigation. The usual differences of temperature between the upper and lower parts of the house result in the movement of gases away from the floor or other points where inward draughts occur, hence, organisms on earth or concrete floors about doors and sometimes on bottom beds may not be killed. To assure complete disinfection, spraying about doors and over empty lower beds with fungicidal solutions, and drenching floors, must supplement fumigation and manure heat. Periodical treatment of walks and aisles after beds are producing is often advisable.

Spraying as Compared with Fumigation.— There are reasons why spraying all interior parts of mushroom houses with fungicidal solutions might well displace fumigation. First, fungicidal solutions are required to treat floors, doorways, and bottom beds in addition to infested yards. Equipment and materials for this purpose can be used equally well for all interior disinfection. In some instances, sprinkling cans and small sprayers may be used, but a power sprayer saves time and labor and promotes efficiency. Second, fumigation must be preceded by a dampening of all surfaces in order to be effective. This requires what is essentially a spraying operation. Third, nonvolatile fungicides have a considerable degree of permanence, better penetration and a preservative action on wood. Fourth, it appears advisable to spray all interior surfaces for the control of heat-resistant fungi like truffle and olive-green mold. Finally, it is a fair question in usual cases whether anything is gained by treating any surfaces but those which are not heated to the point of killing fungi by the fermentation of the manure in the beds.

Exterior Disinfection.— The application of fungicides to all possibly contaminated places about mushroom plants appears to be an essential part of an efficient clean-up after any occurrence of disease or weed fungi. In most

cases it should be a routine practice. The treatment is required to remove as far as possible the likelihood that the spores of fungi will be returned to the houses from the time of spawning until the end of the crop. The treatment should include yards, packing sheds, storage places for casing soil, adjacent paths and roads, trucks, tools and various utensils which become contaminated in emptying infested beds. In the composting ground, it is advisable to clean away old manure down to the soil, loosen the soil surface, and then wet the soil with the fungicidal solution to a depth of two or three inches. Not less than a quart of solution to a square foot is required. It is possible to spread concentrated solutions over proportionately more surface and then spray additional water from a hose, to soak the fungicide into the soil.

Comparative Merits of Different Fungicides.— There are several more or less effective fungicides available. Considering low cost, fungicidal value, penetration, permanence, and preservative action on wood, 1 to 2 per cent copper sulphate solution is one of the best. This solution does not affect mushroom growth in any visible way when applied to boards, as has been shown by experimental tests. Composting ground can be drenched with this solution at very low cost.

Mercuric chloride is superior to copper sulphate in fungicidal value and can be used for most purposes except, possibly, for bed boards. The disadvantages of mercuric chloride are that it has a rapid corrosive action on metals, and that it is very poisonous to man and animals. Styer (14) recommends 4 lbs. to 50 gallons of water for infested ground, but this very concentrated solution is advantageous only in that it saves labor in spreading the material. Further wetting would be required to carry the disinfectant into the soil. If applied in the usual strength of 1-1000 (7 ounces to 50 gallons), mercuric chloride is about twice as costly as copper sulphate for material.

Crude carbolic acid has been used for a number of years to dip boards and drench walks and infested ground. The effective ingredients in this material are a mixture of cresols, or so-called cresylic acid. Crude carbolic acid varies in cresylic acid according to the brand or source. The proportion of water in mixing should be adjusted to give 2.5 per cent of cresylic acid. This material, with a soap spreader, is in general use as a disinfectant or bacteriocidal spray in the control of animal diseases. Crude carbolic acid is less effective than copper compounds for fungicidal purposes, but doubtless is is valuable where it can be applied liberally.

Bordeaux mixture is one of the best fungicidal sprays for living vegetation, but it is not equally satisfactory as a disinfectant. It is a rather colloidal suspension in water, hence it remains almost entirely on the surface of boards or soil. It is not likely to give immediate or complete disinfection, although this may finally occur as boards undergo the warm, humid conditions of heating mushroom houses. Bordeaux mixture is not suitable for soil sterilization.

Lime sulphur is effective against certain fungous diseases of living plants, but it soon breaks down into elemental sulphur and then has little value as a disinfectant.

Some mushroom growers use 1-25 dilution of formaldehyde to spray interiors, or 1-50 dilution to drench soil. These treatments are very effective

for a period. Their disadvantages are rather high cost, lack of permanence, and irritating effects.

Fungi Killed by Compost Heat

Too much reliance may be placed on house disinfection. This may be effective in itself, and is advisable as a rule, yet its value is commonly nullified by organisms returned with infested compost and casing soil. All the objectionable fungi may be and frequently are brought in following the renovation of houses. The prevalence of the fungi in the late stages of mushroom crops is an indication of such introduction. While numerous organisms are brought in with the compost, many enter at spawning, at casing, and during the picking period.

It is fortunate that all the diseases and the more common weed fungi coming into houses with the compost can be killed by the subsequent heat of fermentation in the beds. In recent years, the tendency to use higher temperatures for the peak heat, to facilitate the killing of insects, has been a great benefit in the control of fungi. For this purpose, a temperature of 130° to 140° F. is advisable. This temperature often is not reached by the natural fermentation, or thermogenesis, in the manure, and it is necessary to supplement it with the house heating system. If this does not suffice, it is possible to lay perforated pipes along the center aisle and allow live steam to escape beneath the bottom beds.

Lambert (10) shows that the spores of *Mycogone perniciosa* are killed at the rather low temperature of 106° F. in a period of 6 hours. Ware (20) reports that *Verticillium malthousei* is killed at 104° F. in the same period. The important disease and weed fungi associated with mushroom culture in Pennsylvania were tested by the writer for their ability to survive temperatures commonly obtained in houses during the peak heat of the compost. Tests by exposure in hot water baths were also made. In some tests, duplicate cultures on agar in tubes were used; in others, cultures upon composted horse manure in 250 ml. flasks. These were set in heating beds for 16 to 24 hours, in repeated trials. The following fungi did not survive when the temperature varied from 115° to 120° F.:

Mycogone perniciosa, bubbles;
Verticillium sp., brown spot or fungous spot;
Bacterium sp., brown blotch;
Dactylium sp., soft decay or mildew;
Monilia fimicola, white plaster mold;
Trichoderma koningi, green mold of casing soil;
Cephalothecium sp., mold from casing soil.

This range of temperature did not kill *Pseudobalsamia microspora,* truffle, and *Coprinus atramentarius,* the ink cap, in their spore form, although their mycelia were destroyed. *Chaetomium olivaceum,* the olive-green mold and *Myriococcum praecox,* the brown plaster mold, survived in tests in mushroom beds in which the maximum was 129° F., but not when exposed for six hours in a hot water bath at 140° F.

Species of *Penicillium* and *Aspergillus,* members of the common blue and green mold group of fungi, were isolated from compost after the peak heat in mushroom beds. These molds survived an exposure of six hours at 140° F. in a hot water bath. There is no evidence that they are harmful in compost. Spores or sclerotia of the ink cap survive rather high temperatures in fermenting manure, but the limited development of this fungus as the beds cool, or soon after spawning, is not regarded seriously by most growers.

Lambert (11) reports that the spores of truffle in test tubes survived 180° F. for at least five hours. At The Pennsylvania State College compost heaps and beds at the time of filling were inoculated with spores of truffle. The fungus came to full development during the mushroom bearing period (Fig. 3), although a temperature of 136° F. continuing for two days had been reached by the compost. Other beds in the house, filled at the same time but not inoculated with truffle spores, showed no signs of the fungus.

The tests indicate that temperatures commonly reached in the peak heat of mushroom beds kill the more important harmful fungi, and that 120° F. suffices. The usual long period of heat is doubtless a great factor in destroying the organisms. Among the fungi that escape death, truffle is the most injurious, but its occurrence is not likely to be frequent, as the reports of recent years indicate. The olive-green mold and the brown plaster mold exhibit rather great resistance to heat and may survive occasionally in lower beds.

A maximum of 120° F. is a rather low temperature for the heating of mushroom beds and is not regarded as sufficient to drive insects from the compost or to assure the best results in mushroom production. To drive out insects effectively so that they may be killed by sulphur or cyanide fumigation, a temperature of at least 130° F. in the bottom beds is desirable (18). To obtain this temperature in bottom beds, it is essential that they be eight inches above the ground. Very often, it is necessary to install horizontal fans at the top of the central aisle so as to cause the hotter air in the upper part of the house to circulate downward. This tends to equalize temperatures throughout the house. While it is essential to have the manure become hot enough to kill fungi and drive out insects, it is also important to avoid too high temperatures, as this is known to reduce the production of mushrooms. Excessive drying of the compost is dangerous. It is advisable, therefore, to avoid unnecessarily high temperatures, above 140° F., if possible.

The fact that many organisms enter houses with the compost but are destroyed by subsequent heat causes considerable doubt as to the value of disinfecting houses while they are empty. Proper heating of the beds after filling appears much more important. It is probable, however, that most growers prefer to do too much rather than to risk doing too little in combating insect and fungous enemies, and hence will retain some form of disinfection prior to refilling. Sulphur fumigation is neither costly nor inconvenient and has noteworthy insecticidal value; yet its value in this respect is much greater while the houses are in heat. It is important not to disparage the disinfection of houses, but to emphasize the need of measures to prevent the entrance of organisms during spawning, casing and picking. The oc-

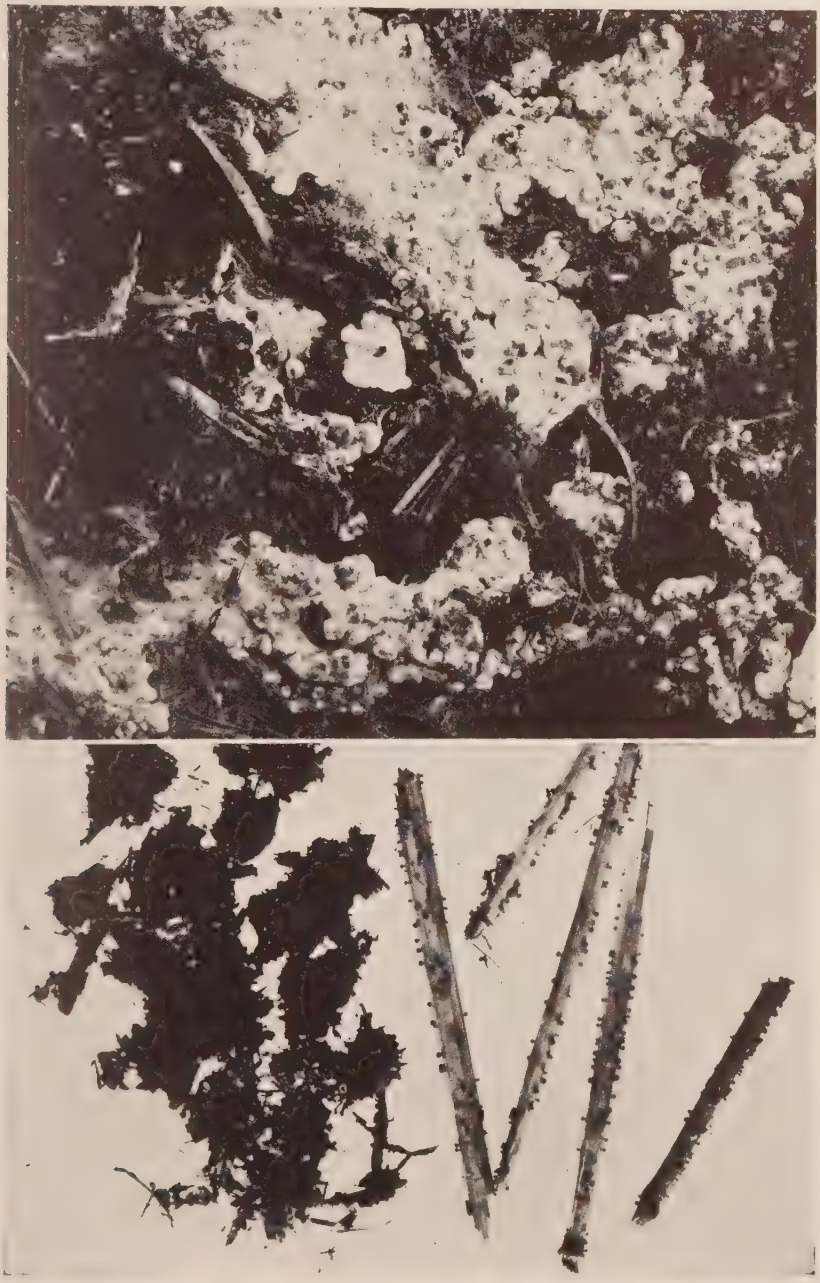

FIG. 3. TRUFFLE AND OLIVE-GREEN MOLD
Above, mycelium and the spore-containing structures of truffle, *Pseudobalsamia microspora,* in the compost of a mushroom bed as seen when the side board of the bed was raised. *Below,* olive-green mold, *Chaetomium olivaceum,* upon the surface of straws and bits of compost showing the tiny spore-containing structures.

currence of at least two important diseases and one mold is due usually, if not always, to entrance through these later operations. These diseases are bubbles, brown spot and white plaster mold.

Sterilization of Casing Soil

This practice has increased since the discovery that soil is the principal carrier of the *Mycogone* disease. Sterilization results in essentially complete control of this disease. Previously, recommendations for the control of the *Mycogone* disease were limited to fumigation of houses and precautions against the spread of spores by insects and workmen (3, 22). That abnormally warm temperatures increased loss had been noted by growers. Efforts at control were of little avail, however, because the chief source of the causal organism was overlooked.

In 1924, Smith (16), in England, reported that the *Mycogone* disease was prevented when the location for beds and the soil for covering them were both treated with formaldehyde. The writer (1) then began soil sterilization with formaldehyde in cooperation with mushroom growers of Chester County, Pa. The casing of beds with treated soil gave crops free of the *Mycogone* disease. Observations indicated that there was little danger of the disease being introduced in other ways than by infested soil, if reasonably sanitary precautions were taken.

The benefits of soil sterilization, not only to control the *Mycogone* disease but also to destroy other harmful fungi and insects, should be strongly urged. After efforts have been made to rid houses and compost of harmful organisms, it is most unwise to cover the beds with soil that is liable to be contaminated with like organisms. The movement of infested soil by surface washing and by wind should be taken into consideration. To reap the full benefits of soil sterilization, however, all other measures of sanitation must be carefully followed, particularly the regular removal of waste materials and the treatment of yards, vehicles, and storage places with fungicides. Unless there is well-rounded sanitation, disappointment may follow through the recurrence of fungi easily disseminated by wind, insects, and workmen, especially *Verticillium* which produces several symptoms like the *Mycogone* disease.

Steam is probably preferable to formaldehyde for the treatment of soil for casing mushroom beds. The main objection to formaldehyde is its failure to kill all insects, although soil is not the chief source of mushroom insects. There appears to be some small danger of overheating soil while steaming, with resulting injury to its water-holding capacity. This objection may not be important, or insurmountable.

It is possible to distribute formaldehyde evenly through large quantities of soil by sprinkling it as it is screened. The chemical is used at the rate of 3 lbs. to a cu. yd. or ton of soil. It can be diluted 20 times with water to aid distribution without making the soil too wet. Formaldehyde might be applied to the soil somewhat in advance of screening rather than after it passes the screen, as was done in the experiments here reported. The screened soil should be left in long narrow piles to facilitate the escape of the fumes. Covering the piles for a day with burlap just after treatment is advisable.

If this treatment is performed in early fall, the fumes will have left the soil before it is stored or placed on beds.

The experiments of Lambert (10) showed that *Mycogone perniciosa* would not survive the moderately high temperatures occurring in mushroom houses during the final fermentation of the manure. This suggested to him the possibility of killing the spores by placing the soil in houses during the period of heat. While this procedure has never been adopted, Lambert's work has promoted the sterilization of soil with steam. Varying methods are in use. It is possible to use steam from the boilers of heating systems as well as from those of steam traction engines as is done with tobacco seedbeds (9).

Methods of Steaming Soil.— A bin with a false or portable bottom offers several advantages in steaming soil when used in a place other than where treated. A bin with tight plank sides is built on the ground. The false bottom consists of boards with wide cracks, or with holes bored at regular intervals, to permit the passage of steam. The outlet for the steam is placed beneath this bottom. It may consist of a frame of perforated pipe, or it may be just a simple T-form, if the bottom is well supported. The board bottom makes it easy to scoop out treated soil, permits the drainage of excess moisture, and may check overheating to some extent. The ground beneath the bin becomes insulated against great loss of heat when it becomes wet. The loss of heat on the upper surface should be checked with a tarpaulin cover. The main advantage of using a bin is to conserve heat.

The size of the bin should suit the capacity of the boiler. A 15 h. p. boiler can supply a 10 by 10-foot bin. The depth of the soil should not be more than 12 to 15 inches. Heating may proceed until all parts of the upper surface reach 130° to 140° F. It is better if the bottom does not rise above 180° F., but it may be impossible to avoid this.

Some mushroom growers have used an adaptation of the bin by laying the fork-shaped frame of perforated pipe on the floor of the truck used to haul the soil. This conserves less heat and offers more difficulty in obtaining uniform distribution, but considerable labor is saved.

Another method is to place an inverted pan, like that used in seedbed sterilization (9), over a bin of soil. Since it is more difficult to drive steam downward, especially after the upper surface becomes wet, the depth of soil cannot be great, not more than eight inches at most, if overheating of the surface is to be avoided. It is important to maintain good boiler pressure so that there may be a maximum of heating and a minimum of wetting the soil.

The cost of steaming soil required for three standard sized mushroom houses was found, in one instance, to be approximately $1.25 for 1000 sq. ft. of bed. In this case, an inverted pan and a traction steam engine boiler of 15 h.p. capacity was used. The cost of sprinkling soil with formaldehyde while screening would be the same as for steaming.

Sanitation Measures During Production

The various fungi occurring in mushroom beds differ greatly in their spread after introduction. The *Verticillium* disease is disseminated very rapidly;

it may occur in a series of houses soon after its introduction. This is due not only to prolific spore production, but also to the fact that only a few days elapse in the course of inoculation, infection, complete development, and new spore formation. The green molds in casing soil, and the mildew caused by *Dactylium* and white plaster mold, are rather similar in this respect. Strong air currents and insects also are important means of scattering these fungi.

The *Mycogone* disease is quite slow in spreading. This is due in part to the considerable time between inoculation and full development. Usually, the abnormally warm conditions required for its development are lacking in well-cared-for houses. The general occurrence of the *Mycogone* disease always indicates an extensive infestation of the casing soil with spores before it was put on the beds. Inoculation tests (4) show that neither of the two spore forms of *Mycogone perniciosa* (chlamydospores and *Verticillium*-like conidia) infect partly developed mushrooms with any ease. The beginning of infection is in the mycelial strands of the mushroom within the casing soil. Chaze and Sarazin (5) regard the relation of the mushroom and *Mycogone perniciosa* as one of mutual parasitism.

An occurrence of truffle is serious, since it stops mushroom production altogether in affected areas, yet there is little likelihood of new centers of the mold being started by picking, watering, air currents, or insects. The explanation of this is that the spores of truffle are not readily released from the fruiting bodies. The widespread occurrence of this mold probably depends on the dispersal of the spores through the compost heaps at turning or during the filling of the beds. It is possible that casing soil becomes contaminated in a similar way.

It is important to prevent, if possible, the spread of such organisms as *Verticillium sp., Dactylium sp.* and *Mycogone perniciosa.* Diseased mushrooms should be removed and destroyed. Unless the workmen exercise great care, they may become the chief agents in spreading the spores through the establishment, as spores adhere to hands and clothes as well as to baskets and utensils. After contact with disease, there should be cleansing of hands and outer clothing before going into clean houses. There should be regular sterilizing of contaminated tools and soiled baskets used in the collection of old butts and other waste from beds. Second-hand baskets, such as those received in exchange at canneries, are dangerous. A solution of formaldehyde or copper sulphate is suitable for spraying contaminated baskets and tools.

Experiments with Fungicides to Control *Verticillium*

In most cases, after an occurrence of *Verticillium* the casing soil is contaminated with spores. Removal of infected mushrooms is only partially effective in checking the spread of the organism. The gradual dissemination of the parasite and the heavy deposit of spores in the casing soil often result in general infection in about the fourth or fifth flush, so that little other than spotted, split-stem, and tiny puffball-like mushrooms develop. When the disease reaches this serious stage, some growers renovate the beds by removing the casing soil along with a shallow layer of the compost, and then

FIG. 4. WHITE-PLASTER MOLD AND CAT'S EAR FUNGUS
Above, white plaster mold, *Monilia fimicola,* upon the surface of the casing soil of a mushroom bed.
Below, cat's ear fungus, *Pleurotus passeckerianus,* collected from the surface of a bearing mushroom bed.

applying fresh soil. This procedure may give one or two flushes that are comparatively free of disease, but serious spotting is quite certain to develop again because numerous spores remain on the compost or elsewhere in the houses. These spores are soon disseminated by insects, watering, and pickers.

There is no satisfactory remedy after beds become badly polluted with *Verticillium* spores and infected mushroom fragments. In such cases, a more effective and less laborious method than recasing would save a large portion of the crop from serious damage. It may appear difficult or impossible to destroy one fungus and save another by the application of a fungicide, as the prevention of *Verticillium* infection of mushrooms would require, yet the nature of mushroom beds does permit this procedure. If the fungicide remains on the surface of the casing soil, or penetrates no farther than this covering, injurious fungi within it can be destroyed to a large extent, though seldom completely. Since most of the spawn is beneath the surface and not affected by the fungicide, new sporophores will continue to develop. Dilute bordeaux mixture (1-1-50 or 2-2-50) and copper-lime dust (containing 10 or 15 per cent monohydrated copper sulphate and no arsenical) do not affect young sporophores seriously when these materials are applied directly to them. Only a small amount of russeting may result. The better practice, however, is to apply fungicides to the casing soil between flushes, after all good mushrooms have been picked, all waste removed, and the surface of the soil scarified. The fungicides may be applied before watering.

Experiments were conducted in applying various fungicides to *Verticillium*-infested beds. Bordeaux mixture and copper-lime dust proved to be the safest, and usually significant reductions in spotting were obtained. Representative results are reported in Table 3. These results were obtained in an experimental house in which the plots, or experimental units, were each of 10 square feet. The plots were separated from each other only by a board partition set into the compost.

The data show the respective numbers of spotted and healthy (entirely unblemished) mushrooms in the flush. The degree of control is not so great as is desirable, yet it is important, and justifies the effort. The results would appear more impressive if the respective numbers of spots, rather than just healthy and infected mushrooms, were the basis of comparison, but since many spots merge, this would be difficult to secure. Usually the infected mushrooms from treated plots were less seriously spotted than those from untreated plots. Occasionally, there was variation in the degree of bed infestation; this is evident in Experiment 5 (Table 3), in which the untreated plot had the advantage of light infestation.

Somewhat comparable control of *Verticillium* was obtained by incorporating formaldehyde with screened soil at the rate of a half pint to a bushel, thoroughly mixed. This formaldehyde-treated soil was scattered evenly over the surface of infested beds, a bushel to 300 to 400 sq. ft. There was some danger of injury in this treatment depending on how advanced pinhead development in the casing soil was. The next flush was delayed and tended to be of fewer but larger mushrooms.

These fungicides were used on a somewhat larger scale in commercial mush-

room houses, with comparable results. Their value depends considerably on the skill of application and the simultaneous efforts to improve environmental conditions that affect the disease. They appear to have greatest value in cleaning up or checking occasional or local occurrences of *Verticillium* disease,

TABLE 3. RESULTS OF SPRAYING MUSHROOM BEDS WITH 1-1-50 BORDEAUX MIXTURE, AND DUSTING WITH 10-90 COPPER-LIME DUST, FOR THE CONTROL OF THE *VERTICILLIUM* DISEASE (BROWN SPOT OR FUNGOUS SPOT)

Experiment	Treatment	Infected or spotted mushrooms	Healthy or clean mushrooms	Per cent of healthy or clean mushrooms
1.	Copper-lime dust	6	79	92.9
	Untreated	22	58	72.5
2.	Bordeaux mixture	8	44	84.6
	Untreated	29	25	45.3
3.	Bordeaux mixture	10	48	82.7
	Untreated	31	13	29.3
4.	Bordeaux mixture	46	48	52.6
	Untreated	45	13	22.4
5.	Bordeaux mixture	10	33	76.7
	Untreated	12	41	77.3
6.	Bordeaux mixture	9	73	90
	Untreated	39	30	43.3
7.	Bordeaux mixture	15	57	79.1
	Untreated	34	15	30.6
	Average of all treated plots			78.8
	Average of all untreated plots			45.8

bubbles, or mildew. Bordeaux mixture or copper-lime dust would be safe on a large scale, but it is possible that formaldehyde would prove quite injurious with a considerable accumulation of fumes.

Regulation of Environmental Conditions

Although emphasis should be placed on sanitation, that, alone, may not be enough. The general distribution of certain fungi and their easy dissemination by wind or other agents makes exclusion difficult when infested houses are near. In such cases, a knowledge of the conditions that promote growth is an advantage. The grower can regulate environment to a considerable extent, and he can choose the season in which the mushroom crop shall be grown. Although the environment that favors the development of the various fungi has much in common with that required for the growth of mushrooms, yet each species has more or less important distinctions with respect to particular environmental factors. Experiments and observations indicate that it is chiefly when environmental conditions, or the preparation of the compost, have not been made optimum for mushrooms that injurious fungi do serious damage.

Temperature.—When thorough sanitation is difficult to obtain, it is a good rule to fill houses but once a year so that mushroom production may

come during the colder seasons, when there is no difficulty in maintaining environmental conditions that hold diseases and molds in check. Temperature not only has a direct influence on the growth of fungi, but also affects humidity, evaporation, and ventilation. These, in turn, have an influence on the germination of fungous spores and the development of the organisms. During the colder months, less watering is required, ventilation is safer and more efficient, and excess moisture dries readily on developing buttons and pinheads. It is easier to maintain the most favorable humidity within houses, and favorable dampness of the casing soil. Harmful fungi are not developing outside as well as inside the houses, and filling the air with their spores.

Spawning is usually done when beds have cooled to 75° F. It is not advisable to maintain this temperature after the spawn starts to grow. Further cooling is better, not only to check diseases and molds, should they be present, but also, to favor more vigorous mushroom mycelium. A good run of spawn may be obtained by holding the beds as low as 60° F., provided the manure is not too damp and is favorably composted. A temperature of 65° F. is suitable for most conditions in the running of spawn. When beds are cased and come into bearing, 55° to 58° F. is recognized as optimum for mushrooms of good quality. If these ranges of temperature were consistently maintained, together with reasonable sanitation, loss from diseases and molds would generally be small. The endeavor to take advantage of the higher prices during warm weather, without efficient cooling and ventilating equipment, is made at the risk of heavy loss from diseases. Satisfactory crops sometimes are grown in spite of a considerable departure from optimum temperatures, but gains in one respect are commonly offset by reduced yields and lower quality. Diseases, molds, and insects are usually responsible for loss of yield and quality.

Lambert (10) shows how temperature affects the development of *Mycogone perniciosa* and loss by bubbles. At 50° F., the disease is limited to occasional infections, although the soil may be heavily inoculated with spores; while at 60° to 70° F., there is 100 per cent infection. Low temperature checks the development of the parasite more than the mushroom. Serious outbreaks of bubbles occur mostly in early fall or late spring when temperature cannot be regulated effectively. When it is possible to bring temperature down to 55° F., or lower, succeeding flushes often show more healthy than deformed mushrooms, provided all originally infected specimens are removed from the beds.

A study was made of the effects of temperature upon the development of some of the diseases and molds of mushroom beds. The rates of growth of the fungi in pure culture were observed at various temperatures in the laboratory, and observations were made under such variations of temperature as were possible in experimental and commercial mushroom houses. Minimum, optimum, and maximum temperatures are given in Table 4. A temperature of 55° F. which is satisfactory for bearing beds, is nearer the minimum than the optimum for most disease and mold fungi. Mushroom mycelium grows slowly even below 45° F., which has been given as its minimum (Table 4). This explains why mushrooms comparatively free from disease can be grown

in spite of rather unsanitary surroundings, provided the temperature is sufficiently low.

TABLE 4. CARDINAL POINTS OF TEMPERATURE FOR CERTAIN FUNGI ASSOCIATED WITH MUSHROOM CULTURE

Fungus	Common name of disease or mold	Minimum	Optimum	Maximum
Mycogone perniciosa	bubbles	48.5° F.	75° F.	90° F. (Lambert)
Verticillium sp.	brown spot	49	74	
Pseudobalsamia microspora	truffle	52	83	97
Chaetomium olivaceum	olive-green mold	49	78*	90
Monilia fimicola	white plaster mold	50	72*	87*
Dactylium sp.	mildew	48	77	90
Bacterium tolaasi	brown blotch	43	77	(Paine)
Agaricus campestris	mushroom	45	73	85

* Approximate.

The unusually high optimum of truffle is noteworthy. Like bubbles, the occurrence of truffle is associated largely with warm weather. If the presence of the mold is suspected, it is advisable to grow the spawn at a temperature as low as is consistent with good practice. To delay filling houses until October or later would accomplish this purpose most readily.

There is little opportunity to control white plaster mold or olive-green mold by the manipulation of temperature. The optimum for each of these molds is too near that required for starting and running spawn, and it is during this period that these molds are harmful. The basis for their control lies more in favorable composting and the pH reaction of the manure.

The temperature ranges of *Verticillium* and *Dactylium* do not differ greatly from that of the mushroom. Low temperature in itself may not check satisfactorily the attack of these parasites under very damp conditions. Much of the value of low temperature depends upon the opportunity to reduce watering and ventilate efficiently. *Verticillium* usually is not serious from October to April, in Pennsylvania, although the parasite may be established in certain places in houses. The conditions essential for the suppression of the *Verticillium* disease are illustrated by an abandoned quarry in Butler County, Pennsylvania, where mushrooms are grown. In one part of this quarry, the temperature remains at 53°F. and in another part, 56° to 57°F., throughout the year. The arrangement of passages and openings to the outside is such that there is always adequate ventilation of the beds, yet humidity is constantly higher than in most mushroom houses, being 96 to 97 per cent. It is not necessary to water bearing beds more than once in about three weeks. Brown spot does not cause significant damage, although *Verticillium* is present. The peculiar condition exists that, although humidity is unusually high, absence of temperature fluctuations prevents the precipitation of moisture upon developing mushrooms.

Humidity and Dampness of Casing Soil.—In mushroom houses there is only a narrow range within which humidity of the air and dampness of the casing soil can be varied for the purpose of checking injurious fungi and at the same time provide favorable conditions for mushrooms. In general, humidity that will limit the frequency of watering beds to once before each flush of mushrooms is most desirable. The necessity of more frequent water-

ing increases the spread of fungous spores and the danger of having spotted mushrooms. Humidity as high as 96 per cent is not objectionable provided there are no fluctuations of temperature and adequate ventilation is possible as in the quarry; but the higher the humidity, the greater the danger that a fall of temperature or the presence of cold draughts will precipitate dew or moisture upon developing mushrooms and throughout the house. This provides the optimum condition for the germination of fungous spores, particularly of *Verticillium*. If this condition cannot be quickly overcome by ventilation, the continuous promotion of disease follows.

A humidity record was kept for two years in a central location in a commercial mushroom house in Chester County, Pa. On the average, 88 to 90 per cent was found to be satisfactory for good mushroom production. The installation of a humidifier that increased humidity to 95 per cent resulted in considerably greater prevalence of *Verticillium* disease, blue-green molds, and white plaster mold. The general increase of dampness throughout the house could not be overcome sufficiently by the ventilation available.

Too high humidity and a tendency toward accumulation of dampness are influenced by the construction of the house, the efficiency of ventilation, and the season of the year. The reduction of dampness by ventilation is directly affected by temperature. Sometimes a rise of temperature is required to start the flow of air. In an experimental house constructed below ground at The Pennsylvania State College, lowering the temperature from 58° to 52° F. did not reduce the prevalence of *Verticillium* disease, because effective ventilation became impossible. The decline of temperature resulted in an increase of humidity to 95 per cent and the walls of the house gathered moisture. The disease was held at a minimum when the temperature was 58° to 60° F.; humidity fell to 88 per cent, and the surface of developing mushrooms remained dry from sufficient changes of air. Infections were limited to 5 to 10 per cent of the sporophores. When humidity was artificially increased at this temperature by allowing escape of steam from a valve, there was a pronounced increase of spotting. During May or later in the spring, the temperature ranged from 60° to 65° F. without heat from the heating system. Humidity then increased to 92 per cent, but ventilation was poor. As in many commercial houses, the *Verticillium* disease then became severe.

Longevity as Influenced by Drying.—The time that spores retain their power to germinate and reproduce the vegetative or actively growing form of a fungus varies considerably. The span of life depends much upon dryness or other adverse conditions, and upon the presence or absence of thick-walled spores or cells (chlamydospores and sclerotia). Most of the fungi occurring in mushroom beds appear equipped to bridge over the periods when mushroom houses are idle. There are at least two species, however, which are comparatively short-lived and quite susceptible to dryness; these are white plaster mold and *Verticillium*. In laboratory tests, the period from the time cultures on agar were started until they were dead because of drying was approximately six months for *Verticillium* and five months for white plaster mold. This indicates that these fungi may die out extensively, if not completely, from May until October. They produce spores very abundantly, but

they are thin-walled. If mushroom culture is confined to the cooler months, the chances that these fungi will become serious are far less than when culture is continued throughout the year.

The Relative Effects of pH on the Growth of Spawn and Competing Molds

Fungi and bacteria are sensitive to the degree of alkalinity or acidity of the food material upon which they grow. As with temperature, the pH reaction may determine the organism that becomes dominant and overgrows a food material, if several competing species happen to be present. Hence it is important that the reaction of the compost shall favor the rapid growth of spawn.

Fresh horse manure may show an acid reaction occasionally which is due, possibly, to organic acids. As a rule, during composting, the reaction of manure undergoes a gradual change from very alkaline (above pH 8.0) to slightly alkaline (pH 7.8 to 7.0), or neutral. For causes not well understood, this change of reaction sometimes is retarded, or even reversed, and the compost remains excessively alkaline. In the absence of competing fungi, spawn may start well anywhere from pH 7.8 to neutral. With very alkaline reactions, however, advantage is given to white plaster mold *(Monilia fimicola)* and also to some extent, to olive-green mold *(Chaetomium olivaceum)*, since both of these molds tolerate much more alkaline conditions than the mushroom. Like many other fungi, the mushroom mycelium, or the spawn, by growth activity, changes the reaction of its food medium to acid.

Having observed that compost in which white plaster mold has grown considerably is very alkaline, usually much more so than that in which spawn grows well, experiments were undertaken to determine whether this mold actually produces the alkaline condition; also observations upon the mold and spawn in competition in the same cultures at varying pH. Horse manure which had been composted for the purpose of making manure spawn, was placed in 250 ml. flasks. Moisture was adjusted to 200 per cent of the dry weight. The range of pH was obtained by the addition of different amounts of acid or alkali. A sample of manure from each flask was taken after sterilization for a test of pH, or separate flasks were prepared for this purpose.

In the first experimental series (Table 5) some flasks were inoculated with both mushroom mycelium and white plaster mold, while others were inoculated with each organism separately. In all cases in which the mushroom mycelium grew alone or became dominant, the reaction became or remained acid (pH below 7.0); but in all cases in which white plaster mold grew alone or became dominant, there was an increase of alkalinity or change from acid to alkaline (pH above 7.0). It is not clear to what degree the growth of white plaster mold was responsible for the increase of alkalinity, for there is a tendency for pH to rise in the absence of any growth (flask 3, Table 5). This same tendency has been noted in mushroom beds. It is certain, however, that the growth of white plaster mold maintains an alkaline reaction, and that this reaction may possibly be increased.

TABLE 5. CHANGES OF REACTION, OR pH, IN MANURE DUE TO THE GROWTH OF MUSHROOM MYCELIUM (*AGARICUS CAMPESTRIS*) AND WHITE PLASTER MOLD (*MONILIA FIMICOLA*)

Flask	pH after sterilization	Inoculum	Relative growth	pH after growth
1.	7.32	Agaricus	Good	6.39
2.	7.7	Agaricus	Good	6.4
3.	7.9	Agaricus	None	8.4
4.	7.9	Monilia	Good	8.47
5.	6.85	Monilia	Moderately good	7.08
6.	7.17	Monilia	Good	7.96
7.	6.95	Monilia	Moderately good	7.49
8.	6.9	Monilia	Moderately good	7.37
9.	6.22	Agaricus-Monilia	Mostly Agaricus with a little Monilia	6.09
10.	7.32	Agaricus-Monilia	Some Monilia at first with Agaricus later	6.37
11.	7.7	Agaricus-Monilia	Nearly all Monilia	8.4
12.	7.78	Agaricus-Monilia	All Monilia	8.5

In a second experimental series, flasks of manure with a range of pH were inoculated with both fungi, and the competition of the two observed. The results are illustrated in Fig. 5. At the very alkaline reactions, pH 8.05 and 7.9, white plaster mold grew readily and took full possession of the manure, except for a slight start of mushroom mycelium at pH 7.9. With somewhat less alkaline reaction, pH 7.6 and 7.05, white plaster mold made relatively less advance against the more rapidly growing mushroom mycelium, which was able to grow into the region first occupied by the mold. When the manure was slightly acid, pH 6.93 and 6.59, the mold made a weaker growth, and the mushroom mycelium took nearly full possession of the manure, including a considerable region which the mold had first occupied. At pH 6.5, the result was the same except that the mold made still weaker growth. With continued increase of acidity, both organisms showed a decline in growth. These experiments show that spawn is better able to compete with white plaster mold as the reaction of the compost becomes less alkaline, or approaches the neutral point of pH 7.0; and that the likelihood of mold growth predominating increases with the rise of pH.

The olive-green mold *(Chaetomium olivaceum)* is adapted to a wide range of pH. Its optimum is pH 6.8, but it grows quite readily at pH 8.0, where the growth of spawn is often inhibited. The growth of this mold upon manure cultures is very rapid and it appears to be toxic to the mushroom mycelium. The mycelium was unable to compete with this mold at any point of the pH scale when flasks of manure were inoculated with both fungi. This fact, together with the rather high temperature required to kill the mold, makes it advisable to disinfect any house thoroughly when it becomes infested.

Species of *Penicillium* and *Trichoderma,* the green molds that occur in casing soil, likewise are adapted to wide ranges of pH. Their abundant growth, however, is favored by very acid conditions. They grow readily from pH 6.0 down to pH 4.5, a range where spawn growth is inhibited; hence very acid soils should be avoided or treated with lime.

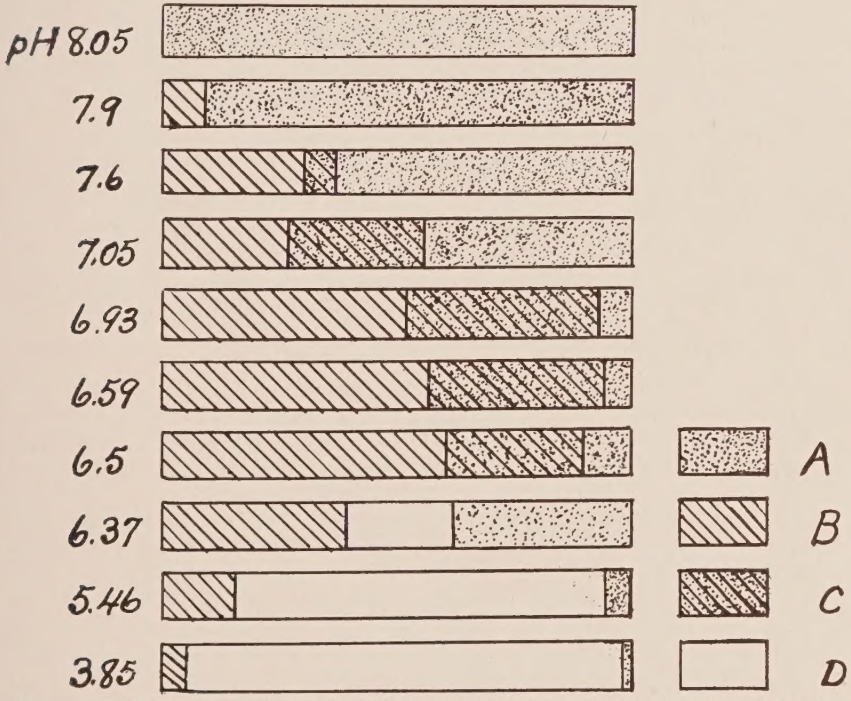

FIG. 5. COMPETITION OR PROPORTIONATE GROWTH OF WHITE PLASTER MOLD AND MUSHROOM MYCELIUM WHEN FLASKS OF COMPOSTED HORSE MANURE WITH VARYING pH WERE INOCULATED WITH BOTH FUNGI

A. Proportion of manure overgrown with white plaster mold.
B. " " " " " mushroom mycelium.
C. " " " " " both fungi.
D. " " " with no growth.

The pH range for truffle *(Pseudobalsamia microspora)* extends from 7.5 to 4.5, with the optimum at 6.8. In comparison with the mushroom, truffle tolerates less alkaline but much greater acid reaction. Spawn will start above pH 7.5, at which truffle is inhibited. This mold doubtless is favored by the acidifying effects of spawn growth, hence it develops after the spawn has run. The usual very alkaline reaction of fresh manure does not permit the growth of truffle, hence it is impractical to determine whether manure is contaminated with the spores of the fungus when received. It is possible that truffle grows in stored manure since acid regions may develop within certain parts of a pile (12).

In experiments with truffle at The Pennsylvania State College, the spores

were distributed in manure at various stages of preparation for mushroom growing, including compost heaps and beds at filling, at spawning, and later. In a large proportion of cases there was no development of the mold; very often the condition of the compost or some environmental factor is not suitable for truffle. In a single filling of the experimental house, all methods of inoculation resulted in the full development of the mold (Fig. 3), but in four other fillings, similar inoculations gave no signs of growth. One explanation of the negative results may be the rather alkaline reaction of the manure at a critical time, as it was spawned at pH 7.6 to 7.8. Good crops of mushrooms were grown.

A considerable range of temperature and dampness of compost was provided, but the results were inconclusive. Another object of the experiments was to determine whether truffle survives in boards that had been contaminated, although exposed to fumigation. The results were inconclusive. A series of flasks of manure prepared for spawn making, with moisture varying from 60 to 360 per cent of the dry weight, was inoculated with truffle spores, including slight bits of broken mycelium. Growth started only above 160 per cent of the dry weight; it began sooner and became heavier as the moisture increased.

Only a few occurrences of truffle were reported by mushroom growers in Pennsylvania from 1934 to 1937. While growers who have had the mold in their houses have endeavored to disinfect properly and remove all infected waste, the negative results in various experiments indicate that the organism often disappears through natural causes.

The factors that influence the reaction of the compost most, or the best procedure to follow in order to obtain the pH most favorable for spawn growth, cannot be stated with certainty. Factors that possibly influence the reaction are the relative amounts of aerobic and anaerobic fermentation in the compost heaps (12), the length of composting, temperature, moisture, ventilation, loss of ammonia, or the chemical changes it undergoes. Since pH usually declines as the final fermentation of the compost progresses in the beds, the most advisable procedure appears to be to prolong this fermentation until a desirable pH is reached.[5]

Mushroom growers have depended upon traditional methods and their sense of the right condition of the compost before cooling beds for spawning. Odor, dampness, texture of the straw and the completion of a given routine of preparation have guided them. In many cases, however, manure in apparently proper condition has remained much too alkaline. Mold growth and the failure of spawn have resulted. Mold growth has been blamed for the failure when the real cause probably has been the unfavorable condition of the compost. Since a test of pH before the beds are cooled will assure the grower of the proper condition of the manure, it seems advisable to use this test in all cases.

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[5] The author is indebted to the experience and counsel of his colleague, Dr. J. W. Sinden, in this discussion of pH of the compost in relation to mold growth.

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